



Activity 3

Orbits and Effects



Goals

In this activity you will:

- Measure the major axis and distance between the foci of an ellipse.
- Understand the relationship between the distance between the foci and eccentricity of an ellipse.
- Calculate the eccentricity of the Earth's orbit.
- Draw the Earth's changing orbit in relation to the Sun.
- Explain how the Earth's changing orbit and its rotation rate could affect its climate.
- Draw the orbits of a comet and an asteroid in relation to the Earth and the Sun.

Think about It

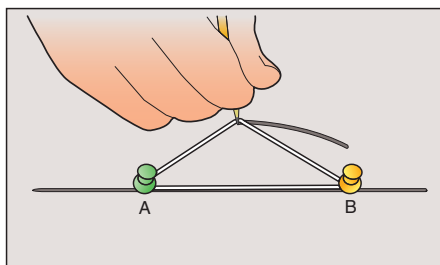
The Earth rotates on its axis as it revolves around the Sun, some 150,000,000 km away. The axis of rotation is now tilted about 23.5° .

- What is the shape of the Earth's orbit around the Sun?
- How might a change in the shape of the Earth's orbit or its axis of rotation affect weather and climate?

What do you think? In your *EarthComm* notebook, draw a picture of the Earth's orbit around the Sun, as seen from above the solar system. Record your ideas about how this shape affects weather and climate. Be prepared to discuss your responses with your small group and the class.

Investigate

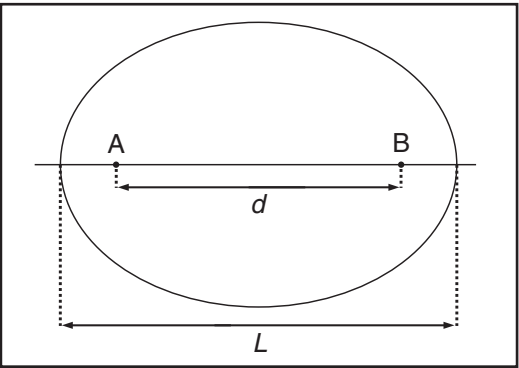
1. Draw an ellipse using the following steps:
 - Fold a piece of paper in half.
 - Use a straightedge to draw a horizontal line across the width of the paper along the fold.
 - Put two dots 10 cm apart on the line toward the center of the line. Label the left dot “A” and the right dot “B.”
 - Tape the sheet of paper to a piece of thick cardboard, and put two pushpins into points A and B. The positions of the pushpins will be the foci of the ellipse.
 - Tie two ends of a piece of strong string together to make a loop. Make the knot so that when you stretch out the loop with your fingers into a line, it is 12 cm long.
 - Put the string over the two pins and pull the loop tight using a pencil point, as shown in the diagram.
 - Draw an ellipse with the pencil. Do this by putting the pencil point inside the loop and then moving the pencil while keeping the string pulled tight with the pencil point.
 - a) Draw a small circle around either point A or point B and label it “Sun.”
2. Repeat the process using the following measurements and labels:
 - Two points 8 cm apart labeled C and D (1 cm inside of points A and B).
 - Two points 6 cm apart, labeled E and F (2 cm inside of points A and B).
 - Two points 4 cm apart, labeled G and H (3 cm inside points A and B).
 - Two points 2 cm apart, labeled I and J (4 cm inside points A and B).
3. Copy the data table on the next page into your notebook.
 - a) Measure the width (in centimeters) of ellipse “AB” at its widest point. This is the major axis, L (see diagram on the next page). Record this in your data table.
 - b) Record the length of the major axis for each ellipse in your data table.
 - c) Record the distance between the two foci, d (the distance between the two pushpins) for each ellipse in your data table (see diagram).
 - d) The eccentricity E of an ellipse is equal to the distance between the two foci divided by the length of the major axis. Calculate the eccentricity of each of your ellipses using the equation $E = d/L$, where d is the distance between the foci and L is the length of the major axis. Record the eccentricity of each ellipse.



Be sure the cardboard is thicker than the points of the pins. If not, use two or more pieces of cardboard.



Ellipse	Major Axis (L) (cm)	Distance between the Foci (d) (cm)	Eccentricity $E = d/L$
AB		10	
CD		8	
EF		6	
GH		4	
IJ		2	



Ellipse with foci AB showing major axis length L and distance between the foci d .

4. Study your data table to find a relationship between the distance between the foci and the eccentricity of an ellipse.
- a) Record the relationship between the distance between the foci and the eccentricity in your notebook.

- b) Think of your ellipses as the orbits of planets around the Sun. Does the distance to the center of the Sun stay the same in any orbit?
- c) Which orbit has the least variation in distance from the Sun throughout its orbit? Which has the most?
5. Earth’s orbit has an eccentricity of about 0.017. Compare this value to the ellipse with the lowest eccentricity of those you drew.
- a) Why does it make sense to describe Earth’s orbit as “nearly circular”?

Reflecting on the Activity and the Challenge

In this activity, you explored a geometric figure called an ellipse. You also learned how to characterize ellipses by their eccentricity. The orbits of all nine planets in our solar system are ellipses, with the Sun at one focus of the ellipse representing the orbit for each planet. As you will see, although Earth’s orbit is very nearly circular (only slightly

eccentric), the shape of its orbit is generally believed to play an important role in long-term changes in the climate. The shape of the Earth’s orbit is not responsible for the seasons. You will need this information when describing the Earth’s orbital relationships with the Sun and the Moon in the **Chapter Challenge**.

Digging Deeper

ECCENTRICITY, AXIAL TILT, PRECESSION, AND INCLINATION

Eccentricity

After many years of analyzing observational data on the motions of the planets, the astronomer Johannes Kepler (1571–1630) developed three laws of planetary motion that govern orbits. The first law states that the orbit of each planet around the Sun is an ellipse with the Sun at one focus. The second law, as shown in *Figure 1*, explains that as a planet moves around the Sun in its orbit, it covers equal areas in equal times. The third law states that the time a planet takes to complete one orbit is related to its average distance from the Sun.

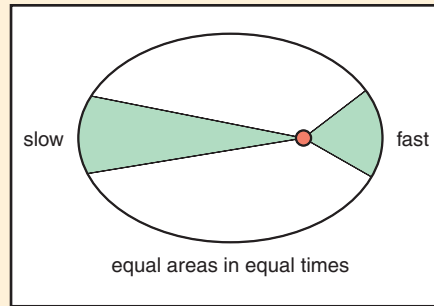


Figure 1 Kepler's Second Law states that a line joining a planet and the Sun sweeps out equal areas in equal intervals of time.

As you saw in the **Investigate** section, the shape of an ellipse can vary from a circle to a very highly elongated shape, and even to a straight line. The more flattened the ellipse is, the greater its eccentricity. Values of **eccentricity** range from zero for a circle, to one, for a straight line. (A mathematician would say that the circle and the line are “special cases” of an ellipse.) The two planets in the solar system with the most elliptical orbits are Mercury, the closest planet, and Pluto, the farthest one. Both have eccentricities greater than 0.2. The orbit of Mars is also fairly elliptical, with an eccentricity of 0.09. In comparison, the Earth's orbit is an ellipse with an eccentricity of 0.017. (This is a much lower value than even the eccentricity of ellipse 1j in the investigation, which looked much like a circle.) If you were to draw an ellipse with an eccentricity of 0.017 on a large sheet of paper, most people would call it a circle. It's eccentric enough, however, to make the Earth's distance from the Sun vary between 153,000,000 km and 147,000,000 km. To make things more complicated, the eccentricity of the Earth's orbit changes over time, because of complicated effects having to do with the weak gravitational pull of other planets in the solar system. Over the course of about 100,000 years, the Earth's orbit ranges from nearly circular (very close to zero eccentricity) to more elliptical (with an eccentricity of about 0.05).

Planetary scientists have found that some solar-system objects have highly elliptical orbits. Comets are a well-known example. As they move closer

Geo Words

eccentricity: the ratio of the distance between the foci and the length of the major axis of an ellipse.



Figure 2 The comet's head or coma is the fuzzy haze that surrounds the comet's true nucleus.

to the Sun, the icy mix that makes up a comet's nucleus begins to turn into gas and stream away. The result is a ghostly looking tail and a fuzzy "shroud," that you can see in *Figure 2*. It is called a **coma**, and it forms around the nucleus. When a comet gets far enough away from the Sun, the ices are no longer turned to gas and the icy nucleus continues on its way.

Another good example is the distant, icy world Pluto. Throughout much of its year (which lasts 248 Earth years) this little outpost of the solar system has no measurable atmosphere. It does have a highly eccentric orbit, and its distance from the Sun varies from 29.5 to 49.5 AU. The strength of solar heating varies by a factor of almost four during Pluto's orbit around the Sun. As Pluto gets closest to the Sun, Pluto receives just enough solar heating to vaporize some of its ices. This creates a thin, measurable atmosphere. Then, as the planet moves farther out in its orbit, this atmosphere freezes out and falls to the surface as a frosty covering. Some scientists predict that when Pluto is only 20 years past its point of being closest to the Sun, its atmosphere will collapse as the temperature decreases.

Axial Tilt (Obliquity)

The Earth's axis of rotation is now tilted at an angle of 23.5° to the plane of the Earth's orbit around the Sun, as seen in *Figure 3*. Over a cycle lasting about 41,000 years, the axial tilt varies from 22.1° to 24.5° . The greater the angle of tilt, the greater the difference in solar energy, and therefore temperature, between summer and winter. This small change, combined with other long-term changes in the Earth's orbit, is thought to be responsible for the Earth's ice ages.

Precession

The Earth also has a slight wobble, the same as the slow wobble of a spinning top. This wobble is called the **precession** of the Earth's axis. It is caused by differences in the gravitational pull of the Moon and the Sun on the Earth. It takes about 25,725 years for this wobble to complete a cycle. As the axis wobbles, the timing of the seasons changes. Winter occurs when a hemisphere, northern or southern, is tilted away from the Sun. Nowadays, the Earth is slightly closer to the Sun during winter (January 5) in the Northern Hemisphere. Don't let anybody tell you that winter happens because the Earth is farthest from the Sun! The Earth's orbit is nearly circular! Also, even if a particular hemisphere of the Earth is tilted towards the Sun, it is not significantly closer to the Sun than the other hemisphere, which is tilted away.

Geo Words

coma: a spherical cloud of material surrounding the head of a comet. This material is mostly gas that the Sun has caused to boil off the comet's icy nucleus. A cometary coma can extend up to a million miles from the nucleus.

precession: slow motion of the axis of the Earth around a cone, one cycle in about 26,000 years, due to gravitational tugs by the Sun, Moon, and major planets.

The precession of the Earth's axis is one part of the precession cycle. Another part is the precession of the Earth's orbit. As the Earth moves around the Sun in its elliptical orbit, the major axis of the Earth's orbital ellipse is rotating about the Sun. In other words, the orbit itself rotates around the Sun! These two precessions (the axial and orbital precessions) combine to affect how far the Earth

is from the Sun during the different seasons. This combined effect is called precession of the equinoxes, and this change goes through one complete cycle about every 22,000 years. Ten thousand years from now, about halfway through the precession cycle, winter will be from June to September, when the Earth will be farthest from the Sun during the Northern Hemisphere winter. That will make winters there even colder, on average.

Inclination

When you study a diagram of the solar system, you notice that the orbits of all the planets except Pluto stay within a narrow range called the **orbital plane** of the solar system. If you were making a model of the orbits of the planets in the solar system you could put many of the orbits on a tabletop. However, Pluto's orbit, as shown in Figure 4, could not be drawn or placed on a tabletop (a plane, as it is called in geometry). Pluto's path around the Sun is inclined 17.1° from the plane described by the Earth's motion around the Sun. This 17.1° tilt is called its orbital **inclination**.

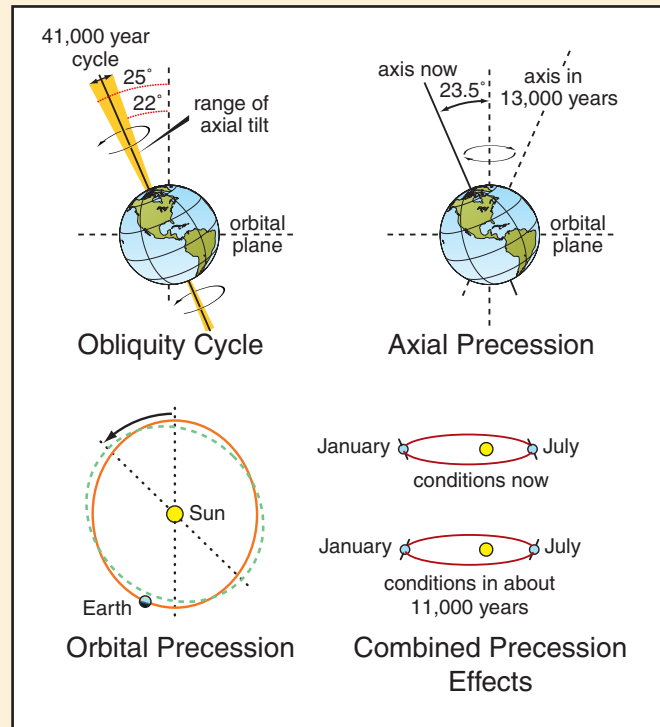


Figure 3 The tilt of the Earth's axis and its orbital path about the Sun go through several cycles of change.

Geo Words

orbital plane: (also called the ecliptic or plane of the ecliptic). A plane formed by the path of the Earth around the Sun.

inclination: the angle between the orbital plane of the solar system and the actual orbit of an object around the Sun.



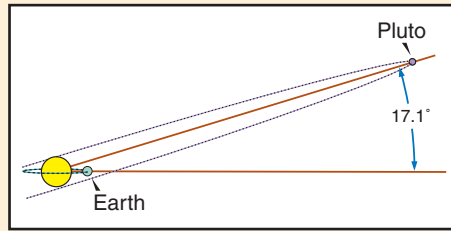
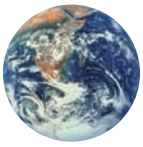


Figure 4 Pluto's orbit is inclined 17.1° to the orbital plane of the rest of the solar system.

What are the orbital planes of asteroids and comets? Both are found mainly in the part of the solar system beyond the Earth. Although some asteroids can be found in the inner solar system, many are found between the orbits of Mars and

Jupiter. The common movie portrayal of the "asteroid belt" as a densely populated part of space through which one must dodge asteroids is wrong. The asteroids occupy very little space. Another misconception is that asteroids are the remains of a planet that exploded.

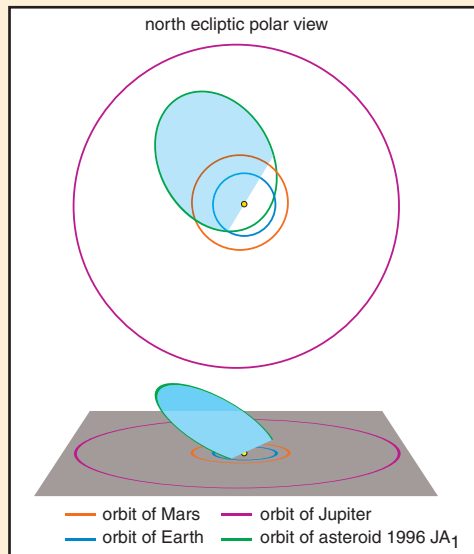


Figure 5 The orbit of the Earth-approaching asteroid 1996 JA₁ in relation to the Earth.

The orbits of asteroids are more eccentric than the orbits of the planets, and they are often slightly inclined from the orbital plane. As the Earth orbits the Sun, it can cross the orbital paths of objects called Earth-approaching asteroids. There is a great deal of interest in finding Earth-approaching or Earth-crossing asteroids. A collision with an object a few miles across could be devastating, because of its very high velocity relative to the Earth.

Astronomers search the skies for asteroids and map their orbits. In this way they hope to learn what's coming toward Earth long before it poses a danger to your community.

Comets are "loners" that periodically visit the inner solar system. They usually originate in the outer solar system. As shown in Figure 5, they have very high-inclination orbits—some as much as 30° from the plane of the solar system. In addition, their orbits are often highly eccentric. Astronomers also search the skies for comets. Once a comet is discovered, its orbit is calculated and the comet is observed as it moves closer to the Sun and changes. A collision of a comet's nucleus with the Earth would be serious, but a collision with a comet's tail is much more likely. A collision with the tail would have little, if any, effect on the Earth, because the tail consists mainly of glowing gas with very little mass.

Check Your Understanding

1. In your own words, explain what is meant by the eccentricity of an ellipse.
2. For an ellipse with a major axis of 25 cm, which one is more eccentric; the one with a distance between the foci of 15 cm or with a distance between the foci of 20 cm? Explain.
3. How does the precession of the Earth's axis of rotation affect the seasons? Justify your answer.
4. Why is there a danger that a large asteroid might strike the Earth at some time in the future?

Understanding and Applying What You Have Learned

1. The major axis of the Earth's orbit is 299,200,000 km, and the distance between the foci is 4,999,632 km. Calculate the eccentricity of the Earth's orbit. How does this value compare to the value noted in the **Digging Deeper** reading section?
2. On the GH line on the ellipse that you created for your **Investigate** activity, draw the Earth at its closest position to the Sun and the farthest position away from the Sun.
3. Refer to the table that shows the eccentricities of the planets to answer the following questions:
 - a) Which planet would show the greatest percentage variation in its average distance from the Sun during its year? Explain.
 - b) Which planet would show the least percentage variation in its average distance from the Sun throughout its year? Explain.
 - c) Is there any relationship between the distance from the Sun and the eccentricity of a planet's orbit? Refer to *Table 1* in the **Investigate** section of **Activity 1**.
 - d) Why might Neptune be farther away from the Sun at times than Pluto is?
 - e) Look up the orbital inclinations of the planets and add them to a copy of the table.

Eccentricities of the Planets	
Planet	Eccentricity
Mercury	0.206
Venus	0.007
Earth	0.017
Mars	0.093
Jupiter	0.048
Saturn	0.054
Uranus	0.047
Neptune	0.009
Pluto	0.249

4. Draw a scale model to show changes in the Earth's orbit of about the same magnitude as in nature (a cycle of 100,000 years).
 - a) Draw the orbit of the Earth with a perfectly circular orbit at 150,000,000 km from the Sun. Use a scale of 1 cm = 20,000,000 km. Make sure that your pencil is sharp, and draw the thinnest line possible.
 - b) Make another drawing of the actual shape of the Earth orbit—an ellipse. This ellipse has 153,000,000 km as the farthest distance and 147,000,000 km as the closest point to the Sun.
 - c) Does the difference in distance from the Sun look significant enough to cause much difference in temperature? Explain.
5. Draw the solar system as viewed from the plane of the ecliptic (orbital plane).



- a) How will Pluto's orbit look with its 17° inclination?
 - b) How will the orbits of the other planets look?
 - c) Draw in the orbits of Earth-crossing asteroids with inclinations of 20° and 30° to the orbital plane.
 - d) Draw in the orbits of several comets with high inclinations. Some typical high-inclination comets are Comet Halley (162.22°) and Ikeya-Seki (141.86°).
6. Now that you know that the Earth's orbit is elliptical (and the Moon's is too), you can think about a third astronomical factor that controls the nature of tides. Tidal forces are stronger when the Moon is closer to the Earth, and when the Earth is closer to the Sun.
- a) Draw a diagram to show the positions of the Moon, Earth, and Sun that would generate the highest tidal ranges (difference in height between high and low tides) of the year.
 - b) Draw a diagram to show the positions of the Moon, Earth, and Sun that would generate the lowest tidal ranges (difference in height between high and low tides) of the year.

Preparing for the Chapter Challenge

1. In your own words, explain the changes in the Earth's orbital eccentricity, and how it might have affected your community in the past. What effect might it have in the future?
2. Describe the orbits of comets and asteroids and how they are different from those of the planets. What effect could comets and asteroids have on your community if their orbits intersected the Earth's orbit and the Earth and the comet or asteroid were both at that same place in their orbits?

Inquiring Further

1. The gravitational "slingshot" effect on spacecraft
The gravitational tug of the Sun and the planets plays a role in shaping the orbits of solar-system bodies. NASA has used the gravitational pull of Jupiter and Saturn to influence the paths of spacecraft like Pioneer and Voyager. Investigate how this gravitational "slingshot" effect works and its role in moving small bodies from one orbit to another.
2. Investigate the orbits of comets and asteroids
Look up the orbital information for some typical comets and asteroids. Try to include some with high inclinations and orbital eccentricities.